Fermilab
ES&H Section

RADIATION PHYSICS NOTE 134

Leachable ^{3}H and ^{22}Na in NuMI Rock Boring Samples

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December, 1999

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I.   **Introduction**

The amount of ^{3}H and ^{22}Na, generated in the the surrounding rock matrix during beam transport, which can be leached out into Fermilab ground waters is of immediate practical interest to the NuMI project in deciding how much shielding is necessary in the NuMI tunnel. A primary purpose for this shielding is to prevent the buildup of ^{3}H and ^{22}Na in surrounding ground water to levels at or above the DOE Derived Concentration Guide (ref. 1) limits for ground water. Therefore what one would really like to know is how much of the ^{3}H and ^{22}Na generated in the rock matrix will show up in the surrounding ground water, i.e., how much of it is leachable. Upon completion of the gamma-ray analyses documented in reference (2), David Boehnlein and Vernon Cupps thought it would be a good idea to attempt to measure the amount of leachable tritium (^{3}H) and ^{22}Na generated in the rock matrix by exposure to the particle beam at the F17 Lambertson magnet. Tritium can be generated within this matrix from spallation reactions on materials with larger mass values, A, than hydrogen or by multiple neutron capture reactions on hydrogen. However, one would not expect multiple step capture reactions to be a major contributing mechanism to the production of ^{3}H in the rock matrix.

The total production of ^{22}Na in the rock matrix was estimated in reference (2) and the amount of ^{22}Na in any leachate can be easily assayed using gamma ray spectroscopy thereby allowing an estimate of the proportion of ^{22}Na leached by a given method.

Tritium presents a more problematic situation with respect to quantifying it within an absorptive medium such as the rock matrix, in that the beta particle which it emits as it decays to ^{3}He is of such low energy that it can not be detected with any reasonable efficiency by external radiation detectors. Hence, the ^{3}H must be extracted from the rock matrix and quantified using a liquid scintillation detection system, a mass spectrometer, or a vacuum system and residual gas analyzer. Because the AAL does not have a mass spectrometer or residual gas analyzer, a liquid scintillation detection system (a Packard 2260XL operating in the low level mode) was used during the course of this study for quantifying ^{3}H in liquid extracts from the rock matrix.

This Radiation Physics Note documents the resulting production of leachable ^{3}H and ^{22}Na in NuMI rock boring samples from exposures to the radiation fields at F17.

II.   **Methods.**

Reference 2 sets forth the basic methods used in exposing the rock core boring samples to beam and processing them for gamma-ray analyses at the Activation Analysis Laboratory (AAL).

During weighing of the rock samples it was noticed that weight losses of a few percent could occur over a period of several hours if the samples were exposed to ambient air. This weight loss reflected the relatively high moisture content (~15%) of the rock samples. To avoid excessive loss of this moisture, the samples were immediately placed back in double zip lock bags after weighing and counting. How much moisture may have been lost prior to transfer of the samples to the AAL is unknown. This is unfortunate since the work of Borak, et. al., (ref. 3), established a clear correlation between the amount of moisture in Fermilab soil samples and the amount of ^{3}H leached from them.

There are several different methods for leaching solid materials such as soils and rock. One method directly mixes water and the solid sample material in varying ratios, centrifuges the mixture, collects the liquid and performs analytical tests on the residual liquid. This method is generically termed the batch or mixing process. However this method does not really simulate the conditions normally found when water moves down through layers of soil and rock. Even so Borak, et. al., observed that under certain conditions this method produces the same results as column percolation methods, in which a predetermined mass of water percolates down through a column of the irradiated material. The water is then collected , and the requisite analytical tests performed on the water samples. For loosely packed matrices, such as sand and soil, this method probably most closely approximates nature; however for closely packed matrices such as rock this is not a feasible approach because it takes far too much time for the water to percolate through even a relatively thin layer of the material matrix . Both of these methods and

various offshoots from them are also discussed in ref 3. Still another method involves heating the solid matrix, collecting the moisture, which comes off, and performing the requisite analytical tests on that water. This method only tells the analyst how much ^{3}H is present in the loosely bound water extant in the solid matrix and like the first method does not really simulate natural conditions. However, if the observations of Borak, et. al., for Fermilab soil (p. 683 of ref. 3.) hold true for the rock matrix then this method may provide a reasonable measurement of the total ^{3}H produced in the rock during irradiation.

For the initial set of four samples (Run 1), we decided to use a slightly different method of simulating ^{3}H and ^{22}Na leaching into the ground water from the rock matrix. After irradiation of 1.08×10^5 seconds, they were soaked in 120 ml of distilled water from 5/15/97 to 10/14/97. The residual water for each sample was then decanted into a 125 ml Nalgene bottle. Gamma-ray spectroscopy was performed on each bottle of residual leachate in order to assay the ^{22}Na content of the leachate. Each leachate sample was then filtered through a 2.7 micron glass microfiber Whatman filter to remove suspended particulates and distilled in preparation for ^{3}H counting.

The second group of samples (Run 2) were exposed to radiation at F17 from 3/28/97 to 4/30/97 but received such a low flux of radiation during that time period that it was decided that leaching tests on these samples would be counterproductive.

A somewhat different approach was taken with the third group of six samples (Run 3). Three samples (1,2, and 4) were soaked in well water from Well 24 for 6 months (indicated in column 8 of Table 1 by 'long term soak') and three samples (3, 5, and 6) were crushed and mixed with Well 24 water for 4 hours (indicated in column 8 of Table 1 by 'mixing'). The Run 3 samples were divided in order to compare results from our new soaking method with those from the more traditional batch or mixing leaching method described above. Well water was used for this group of samples to better mimic what occurs in nature. Upon completion of the allotted leaching time the water residue from each sample was decanted into a 125 ml Nalgene bottle. Each leachate was sequentially filtered using first a 0.2 micron and then a 0.1 micron Gelman hydrophilic polyether sulfone membrane filter to remove suspended particulates. Gamma-ray spectroscopy was performed on each bottle of residual leachate in order to assay the ^{22}Na content of the leachate. Prior to extraction of a 25 ml. aliquot for liquid scintillation counting, each sample was distilled to remove any potential interferences with detection of the ^{3}H. .

Liquid scintillation analysis of the leachates for ^{3}H content required a number of iterations and adjustments to our normal counting methods and protocols. Routinely, we prepare samples for liquid scintillation analysis by placing 2.5 ml of sample and 10 ml. of Ultima Gold A/B scintillation cocktail in a 20 ml plastic vial. After several iterations, we settled on placing 10 ml of sample and 10 ml of Ultima Gold LLT in the 20 ml vial as the combination giving us the best signal to noise ratio for ^{3}H detection. One convenient feature of both our liquid scintillation counting systems is that they allow us to automatically subtract the counts in each spectral region recorded for the first sample vial from all succeeding vials in a given group; commonly referred to as the 'first vial background subtraction' feature. However, it was noted, after some study, that background fluctuations made this feature unusable at ^{3}H concentrations below our routine detection limit of 1 pCi/ml. Therefore this feature was turned off and hand calculations of the ^{3}H concentration in each leachate sample were performed using an average background determined from background samples included at the beginning and end of each group. This allowed us to extend our detection limits down to 0.10 pCi/ml..

III.   Results.

A summary of the various leaching methods and recovered leachate volumes are presented in Table 1. Areas of 11.34 cm^2 and 20.43 cm^2 for the tag and rock discs respectively were used for calculating baryon fluxes in later tables. These particle fluxes were calculated assuming; (1) the particle flux is composed of exclusively protons and neutrons, (2) virtually all particles in the spectrum are well above (i.e. 70 MeV or more) the 30 MeV production threshold, (3) the production cross section for ^{22}Na is nearly constant over the energy spectrum of the interacting baryons, and (4) illumination of the rock core samples was reasonably uniform. Note that the baryon flux determined using the ^{22}Na production cross sections on ^{27}Al at 20 GeV (10.7 mb) and at 1 GeV (14 mb) are listed

in adjoining columns.   The 1 GeV cross section represents the approximate mean cross section between 70 MeV and 20 GeV.

Table 2 lists the baseline ^{22}Na inventory in each sample upon removal from the F17 enclosure as determined by gamma ray spectroscopy. The initial mass and the start and stop dates for the leaching process are also presented in this table.

Results of experimental measurements for the approximate baryon flux, the specific activities of ^{22}Na and ^{3}H in the leachates, and the percent of induced ^{22}Na activity leached out of each sample are presented in Table 3. Determination of the approximate baryon flux was described briefly in reference (1) and will be elaborated on in the Summary and Evaluation section of this note. The approximate baryon flux listed in column 2 of Table 3 was determined by dividing the total baryons incident on each rock sample at a mean energy of 1 GeV by the respective exposure times (both listed in Table 1) and the mean cross sectional areas of the rock core samples, i.e., 20.43 cm^2. Gamma ray spectroscopy was used to measure the specific activity of ^{22}Na in both the base core samples and the leachates. Liquid scintillation was used to determine the ^{3}H specific activity in the leachates.   Determination of the percent ^{22}Na activity leached into water was done by dividing the total activity in the leachate by the total activity in the rock core at the beginning of the leaching process. Comparison of the results from the 4 hour mixing leach method and the 6 month soak leach method, suggested that most of the ^{22}Na is leached out early in the process.

In Table 4, analytical results for the macroscopic cross sections defined by Van Ginneken (ref. 8) and Borak (ref. 3) are derived from the initial ^{22}Na activity measurements. The macroscopic cross section ($\Sigma\, n\sigma$) listed in column 7 is calculated by the formula;

$$\sum_i n_i s_{ij} = \frac{A_j\,(column\ 4\ of\ Table\ 4)\times C\,(0.037\ dps\,/\,pCi)}{\Phi\,(column\ 2\ of\ Table\ 4)\times \left(1-e^{-1_{jt_1}}\right)(column\ 6\ of\ Table\ 4)}$$

from reference 3 with the addition of the saturated activity exponential so that direct comparison could be made with the results of Van Ginneken and Borak. A mean value of $(1.38 \pm 0.06)\times 10^{-4}$ cm^2/gram is obtained from the 10 experimental determinations. Reference 8 lists a value of 1.1×10^{-4} cm^2/gram at 1 GeV for glacial till while reference 3 lists 2.1×10^{-4} cm^2/gram for glacial till, and 1.6×10^{-4} cm^2/gram for gray clay. Agreement is quite reasonable.

The specific activity leached from each rock sample (A_L) is given per gram of the rock sample and not per gram of leachate in Tables 5, 6 and 7. Thus it is calculated by multiplying the leachate specific activity from Table 3 by the leachate recovered volume from Table 1, and then dividing by the rock core sample mass from Table 2 and the total baryons incident on the rock core sample assuming a mean spectrum energy of 1 GeV from Table 1 or the baryon flux assuming a mean spectrum energy of 1 GeV from Table 3 respectively.

$$A_L = \frac{(Column\ 4\ Table\ 3)\bullet(Column\ 10\ Table\ 1)}{(Column\ 3\ Table\ 2)\bullet(Column\ 6\ Table\ 1 \quad or \quad Column\ 2\ Table\ 3)}$$

Table 5 lists the macroscopic cross sections for leachable ^{3}H and ^{22}Na which are calculated in a manner analogous to that outlined for the macroscopic cross sections for Table 4. It should be noted that the macroscopic cross sections for leachable ^{3}H in Table 5 are very much smaller that those given by Borak, et. al., (3) for Fermilab soils. Recall, however, that the present results for ^{22}Na are in very good agreement with those in ref. 3. Further discussion of the low ^{3}H results is given in Section IV.

Tables 6 and 7 present the data of Table 3 per unit baryon and per unit baryon flux as a function of core depth.

IV.   Summary and Evaluation.

Approximate baryon flux is obviously a critical factor in estimating the macroscopic cross sections, the activity per baryon, and the activity per unit flux found in Tables 4 through 7. Foil and/or tag activation is most useful for well defined monoenergetic beams of particles. Clearly this was not the case at the F17 lambertson magnet. Activated tags will not provide us with a knowledge of what types of particles make up the actual flux incident on them or what the approximate incremental energy distribution (i.e. energy spectrum) for them is. So we must either model the proton loss at F17 or make some reasonable assumptions which make modeling unnecessary. In order to calculate a baryon flux from the activity induced in tag or foil one must know the cross section for the nuclear reaction responsible for inducing that activity, in this case, $^{27}Al(n, 4n2p)^{22}Na$ or $^{27}Al(p, 3n3p)^{22}Na$, as a function of particle energy. For monoenergetic protons or neutrons of 20 GeV energy, Cummings (ref. 5) lists the production cross section as 10.7 mb. This is the production cross section used in reference (2) to estimate baryon fluxes. From 70 MeV to 20 GeV the excitation function for the ^{22}Na production cross section on ^{27}Al is a slowly declining function from approximately 19 mb to 10.7 mb (p 194 of ref. 6). Thus for a relatively broad spectrum of proton/neutron energies the ^{22}Na production cross section can be regarded as approximately constant. Table 1 lists the approximate baryon flux determined using 20 GeV and 1 GeV (14 mb cross section) respectively as the mean energy of the baryon flux. The net result is a difference of approximately 30% in the total incident baryons determined at the two different energies. Baryon fluxes determined by assuming a mean baryon energy of 1 GeV were used to determine the derived data presented in Tables 4 through 7. If time allows a full MARS or CASIM simulation to be performed modeling the full energy distribution at F17, the results will be compared with this assumption. Any resulting corrections to the data will be published in a subsequent Radiation Physics Note.

In ref. 4 Wehmann and Childress suggest that the leaching of ^3H and ^{22}Na proceed by different mechanisms. Borak, et. al. (ref. 3), observed that ^{22}Na once leached out of soil can leach back into the soil as it migrates toward the ground water while no measurable amounts of the ^3H in radioactive leach waters migrates back into the soil as it moves through uncontaminated soil. Whether or not this can be applied to the shale/dolemite rock is an open question. Nonetheless, they reason that the amount of transferable ^3H in a matrix, such as the Fermilab dolemitic rock tested in this project, depends entirely on the amount of water in the sample during irradiation. In terms of relative production rates this does make some sense since the cross section for production of ^3H on oxygen nuclei is particularly high; 33 mb (p. 419 of ref. 7). If this reasoning can be applied to the dolemitic shale rock, and the samples tested in this project dried out significantly before the irradiation process, then it is probable that the measurements of leachable ^3H in this present study would be much lower than expected.

Induced ^{22}Na specific activity per unit baryon in the rock core samples remained relatively constant with the boring depth as previously documented in reference 2.

Reference (1) sets forth the regulatory guidelines which DOE and Fermilab use for evaluating the radionuclide concentrations in water. For ground waters, the maximum allowable concentrations of ^3H and ^{22}Na respectively are 20 pCi/ml and 0.4 pCi/ml. The results of this study - particularly those for ^{22}Na – allow, along with a determination of the total inelastic cross section, the calculation of the quantities K_i and L_i (defined in ref. 9) (or the product K_iL_i in the case of ^3H). These values can then be used in the so called Concentration Model, described in Fermilab EP Note 17 (ref. 9), to determine concentrations that can be compared with the regulations.

Finally, observations or guidance drawn from these results should be done so with the caveats in mind that they represent a extremely small statistical sample and are subject to possible unknown preconditioning of the samples tested, i.e., drying out of the samples prior to the irradiation process.

V.   Acknowledgement.

The authors would like to gratefully acknowledge the assistance provided by Alex Elwyn in reviewing and commenting on the initial drafts of this note.

VI.   References

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2. V. Cupps, <u>Residual Gamma Emitting Radionuclides in NuMI Rock Boring Samples</u>, Fermilab Radiation Physics Note 133, February 1999.

3. T.B. Borak, et. al., <u>The Underground Migration of Radionuclides Produced in Soil Near High Energy Proton Accelerators</u>, *Health Physics*, Pergammon Press, Vol. 23 (Nov. 1972), pp. 679-687.

4. A. Wehmann and S. Childress, Tritium Production in the Dolomitic Rock Adjacent to NuMI Beam Tunnels, Fermilab –TM-2083, May 1999.

5. J.B. Cumming, <u>Monitor Reactions for High Energy Proton Beams</u>, *Annual Reviews of Nuclear Science*, p281, 1963.

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7. R.H. Thomas and G.R. Stevenson, <u>Radiological Safety Aspects of the Operation of Proton Accelerators</u>, *Technical Report Series N. 283*, International Atomic Energy Agency, Vienna, 1988.

8. A. Van Ginneken, <u>Na^{22} Production Cross Section in Soil</u>, Fermilab TM-283, 1101.3, January 15, 1971.

9. J.D. Cossairt, et. al., <u>The Concentration Model Revisited</u>, Fermilab EP Note 17, June, 1999.

Table 1
Leaching Methods Summary

Sample ID#	WR #	Core Depth (ft)	Run #	Total Baryons on rock sample at mean energy of 20 GeV (baryons) (X10^{13})	Total Baryons on rock sample at mean energy of 1 GeV (baryons) (X10^{13})	Exposure Time (sec) (X10^5)	Leaching Method	Initial Volume Added (ml)	Recovered Leachate Volume (ml)
970318GL01	97-057	185	1	8.938	6.831	1.08	Long term Soak	120	112
970318GL03	97-057	130	1	11.94	9.125	1.08	Long term Soak	120	116
970318GL05	97-057	138	1	9.844	7.524	1.08	Long term Soak	120	114
970318GL07	97-057 L7	107	1	9.010	6.886	1.08	Long term Soak	120	116
970930GL01	97-269 L1	124.5	3	19.40	14.83	111.18	Long term Soak	120	99
970930GL02	97-269 L2	200	3	14.482	11.07	111.18	Long term Soak	120	94
970930GL04	97-269 L4	125	3	23.71	18.12	111.18	Long term Soak	120	94
970930GL03	97-269 L3	157.5	3	19.72	15.08	111.18	Batch (Mixing)	60	48
970930GL05	97-269 L5	153	3	15.82	12.09	111.18	Batch (Mixing)	65	52
970930GL06	97-269 L6	200	3	16.82	12.86	111.18	Batch (Mixing)	50	41

Table 2
^{22}Na Baseline Inventory

Sample ID#	Reference Date	Core Mass (gms)	Measured ^{22}Na Specific Activity on Reference Date (pCi/gr)		Error on Reference Specific Activity (pCi/gr)	Start Date of Leaching Process	Stop Date of Leaching Process
970318GL01	3/18/97	31.3	111.4	±	19.8	5/15/97	10/14/97
970318GL03	3/18/97	41.3	132.6	±	23.1	5/15/97	10/14/97
970318GL05	3/18/97	31.3	124.7	±	21.8	5/15/97	10/14/97
970318GL07	3/18/97	39.2	105.2	±	18.4	5/15/97	10/14/97
970930GL01	9/30/97	64.9	209.4	±	36.4	3/6/98	9/8/98
970930GL02	9/30/97	59.4	157.4	±	27.4	3/6/98	9/8/98
970930GL04	9/30/97	52.7	260.3	±	45.2	3/6/98	9/8/98
970930GL03	9/30/97	59.1	224.6	±	32	8/31/98	8/31/98
970930GL05	9/30/97	65.4	178.5	±	31	8/31/98	8/31/98
970930GL06	9/30/97	49.5	195.7	±	34	8/31/98	8/31/98

Table 3
Experimental Results

Boring Core Sample ID #	Approximat Baryon Flux at mean Energy of 1 GeV (brns/cm^2-sec)(X10^5)	Radionuclide	Leachate Specific Activity (pCi/ml)		Error in Leachate Activtiy (pCi/ml)	Induced Core Specific Activity at start of leaching process (pCi/gr.)		Error in Induced Core Activity (pCi/gr.)	Percent of Induced Activtiy leached (%)
970318GL01	309.6	^{22}Na	0.71	±	0.16	107	±	19	2.4
		^{3}H	0.15	±	0.04				
970318GL03	413.6	^{22}Na	0.41	±	0.09	127	±	22	0.9
		^{3}H	0.12	±	0.04				
970318GL05	341.1	^{22}Na	0.51	±	0.11	120	±	21	1.5
		^{3}H	< 0.1	±					
970318GL07	312.2	^{22}Na	0.31	±	0.06	101	±	18	0.9
		^{3}H	< 0.1	±					
970930GL01	6.529	^{22}Na	1	±	0.25	187	±	32	0.8
		^{3}H	0.33	±	0.04				
970930GL02	4.874	^{22}Na	2.6	±	0.53	140	±	24	2.9
		^{3}H	0.73	±	0.05				
970930GL04	7.979	^{22}Na	1.03	±	0.31	232	±	40	0.8
		^{3}H	0.16	±	0.04				
970930GL03	6.638	^{22}Na	0.88	±	0.24	200	±	29	0.4
		^{3}H	0.68	±	0.05				
970930GL05	5.322	^{22}Na	1.67	±	0.42	159	±	28	0.8
		^{3}H	0.52	±	0.05				
970930GL06	5.662	^{22}Na	3.15	±	0.87	175	±	30	1.5
		^{3}H	0.53	±	0.05				

Table 4

Derived Analytical Results I
Macroscopic Cross Sections at Saturation

Boring Core Sample ID #	Approximate Baryon Flux (baryons/cm^2-sec)(X10^5)	Radionuclide	Induced Specific Activity (pCi/gr.)		Error in Specific Activtiy (pCi/gr.)	Saturation Factor (X 10^{-4})	Macro X-Section (cm^2/gr.) (x 10^{-4})		Error in Macro X-Section (cm^2/gr.) (x 10^{-4})
970318GL01	309.6	^{22}Na	111.4	±	19.8	9.1128	1.4609	±	0.2597
970318GL03	413.6	^{22}Na	132.6	±	23.1	9.1128	1.3017	±	0.2268
970318GL05	341.1	^{22}Na	124.7	±	21.8	9.1128	1.4843	±	0.2595
970318GL07	312.2	^{22}Na	105.2	±	18.4	9.1128	1.3681	±	0.2393
970930GL01	6.529	^{22}Na	209.4	±	36.4	895.84322	1.3246	±	0.2303
970930GL02	4.874	^{22}Na	157.4	±	27.4	895.84322	1.3338	±	0.2322
970930GL04	7.979	^{22}Na	260.3	±	45.2	895.84322	1.3474	±	0.2340
970930GL03	6.638	^{22}Na	224.6	±	32	895.84322	1.3975	±	0.1991
970930GL05	5.322	^{22}Na	178.5	±	31	895.84322	1.3853	±	0.2406
970930GL06	5.662	^{22}Na	195.7	±	34	895.84322	1.4275	±	0.2480

Table 5

Derived Analytical Results II
Leachate Macroscopic Cross Sections at Saturation

Boring Core Sample ID #	Approximate Baryon Flux (baryons/cm²-sec)(X10⁵)	Radionuclide	Specific Activity Leached (pCi/gr.)		Error in Specific Activtiy (pCi/gr.)	Saturation Factor (X 10⁻⁴)	Macro X-Section (cm²/gr.) (x 10⁻⁶)		Error in Macro X-Section (cm²/gr.) (x 10⁻⁶)
970318GL01	309.6	^{22}Na	2.54	±	0.57	9.1128	3.3311	±	0.7475
	309.6	^{3}H	0.54	±	0.14	1.9238	3.3546	±	0.8697
970318GL03	413.6	^{22}Na	1.15	±	0.25	9.1128	1.1289	±	0.2454
	413.6	^{3}H	0.34	±	0.11	1.9238	1.5810	±	0.5115
970318GL05	341.1	^{22}Na	1.86	±	0.4	9.1128	2.2140	±	0.4761
	341.1	^{3}H	< 0.36	±		1.9238	2.0298	±	**LTV**
970318GL07	312.2	^{22}Na	0.92	±	0.18	9.1128	1.1965	±	0.2341
	312.2	^{3}H	< 0.30	±		1.9238	1.8481	±	**LTV**
970930GL01	6.529	^{22}Na	1.53	±	0.38	895.84322	0.9679	±	0.2404
	6.529	^{3}H	0.5	±	0.06	191.11588	1.4826	±	0.1779
970930GL02	4.874	^{22}Na	4.11	±	0.84	895.84322	3.4828	±	0.7118
	4.874	^{3}H	1.16	±	0.08	191.11588	4.6076	±	0.3178
970930GL04	7.979	^{22}Na	1.84	±	0.55	895.84322	0.9524	±	0.2847
	7.979	^{3}H	0.29	±	0.07	191.11588	0.7036	±	0.1698
970930GL03	6.638	^{22}Na	0.71	±	0.19	895.84322	0.4418	±	0.1182
	6.638	^{3}H	0.55	±	0.04	191.11588	1.6041	±	0.1167
970930GL05	5.322	^{22}Na	1.33	±	0.33	895.84322	1.0322	±	0.2561
	5.322	^{3}H	0.41	±	0.04	191.11588	1.4915	±	0.1455
970930GL06	5.662	^{22}Na	2.61	±	0.72	895.84322	1.9039	±	0.5252
	5.662	^{3}H	0.44	±	0.04	191.11588	1.5045	±	0.1368

Table 6
Derived Analytical Results III

Boring Core Sample ID #	Core Depth (ft)	Radionuclide	Specific Activity leached per incident baryon (pCi/gr-baryon) (x10^{-14})		Error in Leached Activtiy (pCi/gr-baryon) (x10^{-14})	Induced Core Specific Activity at start of leaching process per incident baryon (pCi/gr-baryon) (x10^{-14})		Error in Induced Core Activity (pCi/gr-baryon) (x10^{-14})
970318GL01	185	^{22}Na	3.72	±	0.84	157	±	28
		^{3}H	0.79	±	0.21			
970318GL03	130	^{22}Na	1.26	±	0.28	139	±	24
		^{3}H	0.37	±	0.12			
970318GL05	138	^{22}Na	2.47	±	0.53	159	±	28
		^{3}H	< 0.48					
970318GL07	107	^{22}Na	1.33	±	0.26	147	±	26
		^{3}H	< 0.43					
970930GL01	124.5	^{22}Na	1.03	±	0.26	126	±	22
		^{3}H	0.34	±	0.04			
970930GL02	200	^{22}Na	3.72	±	0.76	126	±	22
		^{3}H	1.04	±	0.07			
970930GL04	125	^{22}Na	1.01	±	0.31	128	±	22
		^{3}H	0.16	±	0.04			
970930GL03	157.5	^{22}Na	0.47	±	0.13	133	±	19
		^{3}H	0.37	±	0.03			
970930GL05	153	^{22}Na	1.10	±	0.28	132	±	23
		^{3}H	0.34	±	0.03			
970930GL06	200	^{22}Na	2.03	±	0.56	136	±	23
		^{3}H	0.34	±	0.03			

Table 7

Derived Analytical Results IV

Boring Core Sample ID #	Core Depth (ft)	Radionuclide	Activity leached from sample per unit flux (pCi-cm^2-sec/gr-baryon) (x10^{-8})		Error in Leached Activtiy (pCi-cm^2-sec/gr-baryon) (x10^{-8})	Induced Core Specific Activity at start of leaching process per unit flux (pCi-cm^2-sec/gr-baryon) (x10^{-8})		Error in Induced Core Activity (pCi-cm^2-sec/gr-baryon) (x10^{-8})
970318GL01	185	^{22}Na	8.21	±	1.85	346	±	61
		^{3}H	1.74	±	0.46			
970318GL03	130	^{22}Na	2.78	±	0.61	307	±	53
		^{3}H	0.82	±	0.27			
970318GL05	138	^{22}Na	5.45	±	1.17	352	±	62
		^{3}H	< 1.07					
970318GL07	107	^{22}Na	2.94	±	0.57	324	±	58
		^{3}H	< 0.95					
970930GL01	124.5	^{22}Na	234	±	58	28646	±	4902
		^{3}H	77.1	±	9.3			
970930GL02	200	^{22}Na	844	±	172	28724	±	4924
		^{3}H	237	±	16			
970930GL04	125	^{22}Na	230	±	69	29076	±	5013
		^{3}H	35.8	±	8.9			
970930GL03	157.5	^{22}Na	108	±	29	30130	±	4369
		^{3}H	83.2	±	6.1			
970930GL05	153	^{22}Na	249	±	63	29876	±	5261
		^{3}H	77.7	±	7.5			
970930GL06	200	^{22}Na	461	±	127	30908	±	5298
		^{3}H	77.5	±	7.3			